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Paper Session I-B - Reliability, Recovery, and Reuse the Three R's of a National Launch Strategy

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Reliability, Recovery, and Reuse
The Three R's of a National Launch Strategy

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Background

The United States is approaching the 21st century with it's space launch community providing only 1960 technology systems with unimpressive success records and with serious deficiencies in operational responsiveness and commercial viability. The current expendable systems have demonstrated launch success ratios of 0.85 to 0.95 with launch costs two to five times higher than the world class competition. The present U.S. Space Launch Infrastructure cannot support achievement of our National Space goals for Defense, Space Communication, SSF Logistics, and Exploration. Over the past 10 years, we have witnessed our share of the commercial satellites launched dwindle from 100% to less than 25%. We recovered from a series of major launch failures in the mid '80's but have been plagued again in '91 and '92 with major launch system failures.

This environment creates a spiral that keeps our launch systems in a state of "limbo" or no change (see figure 1). Since it is so expensive to operate our current fleet of launch systems, it rolls up to very high cost space programs. This prevents us from starting new programs, resulting in less payloads, which feed the rationale to keep our existing fleet. This death spiral must be broken in order for the U.S. to regain its lead in the world launch vehicle market.

These non-complementary efforts by DoD and NASA were further confused by the national Aerospace Plane (NASP) and SDIOs Single Stage to Orbit programs causing Congress to cancel the NLS program in their 1993 deliberations. They have asked that agencies return this spring with an affordable National Strategy which accommodates real and documented needs.

Future Choices

The nation has several options to pursue all with significant consequences (see figure 2). They are; (1) *Do Nothing* - This temptation to do nothing is strong, however the long term DoD/NASA cost penalty is large and we will find ourselves out of the commercial space launch business in the next decade; (2) *Upgrade the current systems* - The current family (Shuttle, Titan, Atlas, Delta, etc.) can be upgraded/enhanced but will still carry the high cost and poor operational features of the 1960/1970 technology. The end result is that we can spend a significant amount of money in upgrading these systems and still end up being non-competitive in comparison to newly developed foreign systems in the next decade; (3) *Develop Separate NASA and Air Force Vehicles* - Proceed with separate developments by NASA and the Air Force - NASA to focus on a heavy lift vehicle or Shuttle replacement for eventual manned exploration and the Air Force to focus on a single vehicle to replace the Titan/Atlas/Delta. Share common development articles where efficient (e.g., engines, upper stages, avionics). The NLS program was moving in this direction just prior to Congressional cancellation; (4) *Leap-frog to a fully recoverable Space Plane* - One need only watch a normal launch of a large existing booster and the associated "loss" of expensive expendable hardware to envision the possible benefits of a fully recoverable SSTO, NASP, HSCT, etc. The temptation is to jump ahead to achieve the very low cost per flight numbers that proponents of these systems project. In reality, technology is not available in the near term, the up front development costs are very high (3 to 4 times the costs of more conventional booster systems) and the low cost per flight numbers are feasible only with very high traffic rates - well in excess of the current projections for the 2000 to 2020 time period; (5) *Build a 20-50K NLS/Spacelifter* - Develop a highly reliable system that will be an economic break-thru for the space launch business in the same way that the 707 paved the way for the air transport business. Provide the dependability, responsiveness, and commercially attractive features to dominate the space launch business in the next century. Build the system initially as an unmanned launch vehicle replacement for Titan/Atlas and use these initial missions to verify the system as a manned launch vehicle. Develop a parallel PLS/upper stand and CRTV to enable the phaseout of the Shuttle.

Proposed Solution

Boeing has participated in numerous government contract studies and independently examined many launch system alternatives over the last eight years. There are two hard conclusions that have repeatedly been reached in all these studies as well as reinforced by our experience with commercial airplanes: (1) *A new launch system must offer a major improvement in launch reliability*. The true cost of failure measured in monetary and non-monetary and non-monetary terms make 99+% reliability a key and obtainable goal of a new launch system (see figures 3 & 4); (2) *Launch costs must be drastically reduced while maintaining an affordable development cost.* The single most significant means to reduce the cost per launch is to recover and reuse high value hardware elements (see figure 5). The most effective means of minimizing development cost is to develop a single "core vehicle" with modular elements that can be integrated to form launch vehicles of varying payload capacities (see figure 6). By developing a system that meets these two "goals", we also achieve the desired improvements in dependability, operational features, responsiveness, commercial development risk reduction. For example:

- High reliability and low cost per launch bring commercial viability and world class competitiveness along with a major reduction in total cost of launch (i.e., reduced cost of failure).

- Recovery/reuse of high value elements makes the technology of automated vehicle health monitoring affordable, which enables improvements in operability, dependability, and responsiveness.

- Recover/reuse of the engine the cost per flight and also makes the total system less sensitive to the per unit cost risk of the engine since an increase in engine cost of 50 or even 100% is reduced by a factor of 8-10 reuse.

The system solution is summarized in figure 7.

The following are additional features and benefits of our recommended solution:

- Recover/reuse of high value hardware can reduce the cost per launch by 47% compared to expendable launch systems. The 2% non-recurring cost penalty is paid back within two flights. This results in a projected life cycle cost savings of multi-billion dollars compared to a conventional expendable launch vehicle system.

- High reliability requires adoption of an "engine out" operating philosophy. Just as with modern transport aircraft that are designed to "fail safe" with one engine out, so must the modern space launch system be able to successfully complete its mission with one engine failed. This is mandatory for a multi-engine launch vehicle to achieve high reliability levels.

- No new engine development is necessary although the STME could be phased-in in the future for additional cost reduction. Use of the SSME LO2/LH2 engines provides high performance without environmental issue.

- Modular redundant systems are cost effective when systems are recovered and reused and thus the "minimum equipment list" philosophy used in the aircraft industry is also viable for the space launch business. This enables highly dependable/high responsive launch operations. Space launch operations finally become "routine and uneventful" just as our airline operations have become.

- The proposed system solution meets the program goals using today's demonstrated technologies. No advanced technology risk is necessary.

<u>Supporting Rationale</u>

The requirements and the mission model have been validated. The government and industry have spent $500M and 6 years of effort by our top engineering teams to identify system architectural options and resolve the technical issues. The technical base is firm.

- Feasibility of recovery has been demonstrated in a technology risk mitigation program which was structured to address each issue in question. *The last page of this presentation is a summary of the 10-minute video of the Advanced Development Program (ADP) which validated the Propulsion Module Recovery/Reuse Concept.*

- Conservative cost analysis based upon Shuttle derived actual costs for recovery/refurbishment operations.

- Recovery concept based upon proven Apollo approach. No advanced technology issues involved.

Critical Need

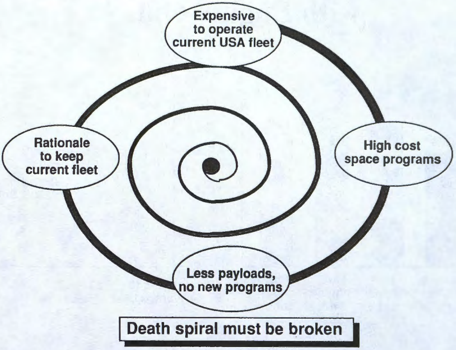


Figure 1

A Wide Range of Spacelift Alternatives

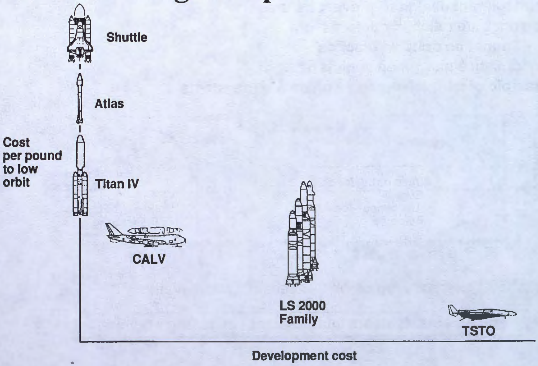
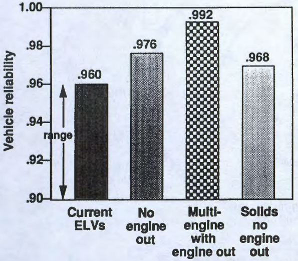


Figure 2

High Reliability Achievable with Engine-Out



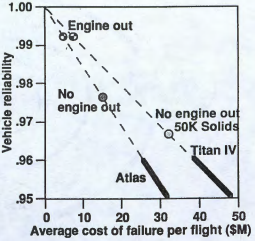
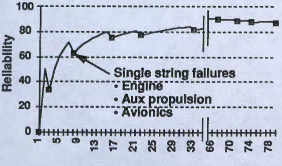
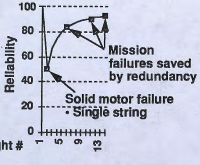


Figure 3

The Reliability Solution

- Fault tolerant design to prevent failures
- Demonstrate reliability before flight
  - Cannot be done with solids
- Performance margin on vehicle design
- Example of fault tolerance avionics & subsystems





- With fault tolerant propulsion 99+ reliability achievable

Make all subsystems fault tolerant - including engines

Figure 4

Motivation for Recovery

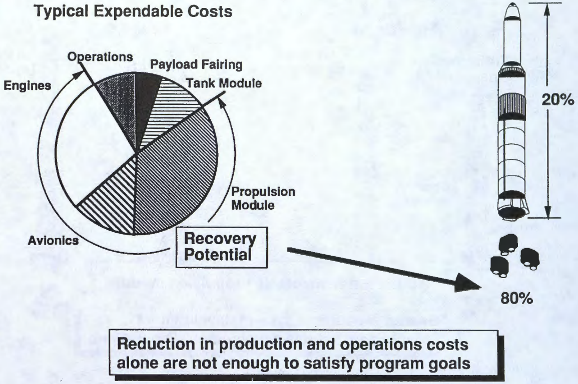


Figure 5

Partially Reusable, Modular System

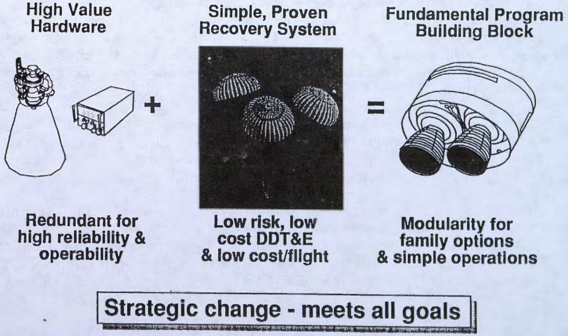


Figure 6

Proposed National Spacelift Program

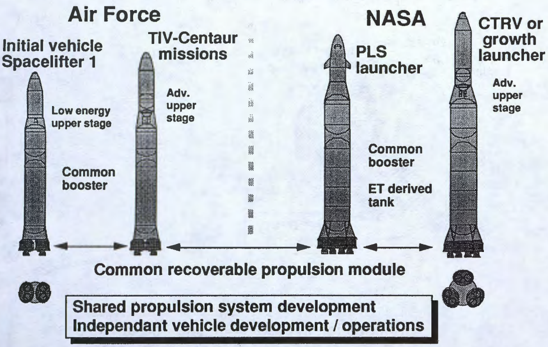


Figure 7

Conclusion

The Government team must show that the program can be accomplished without major increase in the NASA/DoD budget. The savings by transitioning from the Titan, Atlas and Shuttle systems will off-set the development cost of the system. The potential for contractor cost sharing by establishing incentives to invest such as investment tax credits, or the allowance of interest costs should be examined to encourage commercial participation.

The Government must show that the development of the partially reusable system is the natural evolution toward the fully reusable advanced generation solution. As the traffic expands and the technology matures, the "space plane" becomes the evolutionary result.

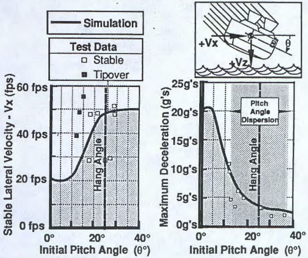
The partially recoverable, modular system offers the technical and operational innovations, dramatic cost reductions and high reliability that will be enthusiastically supported by Congress and the general public. The studies have been done. The system is ready to go into DEM/VAL.

Propulsion Module Recovery ADP Results

Reentry Aero/Aerothermal Tests: 57 hypersonic wind tunnel aerothermal test runs were made in which paint melt, oil flow and shadowgraph data were gathered. Heating data were used to define requirements for an ablative thermal protection system. 204 hypersonic and transonic aerodynamic wind tunnel runs were made in which force and moment, Schlieren and oil flow data were gathered. Tests proved the module to be aerodynamically stable and controllable.

Water Landing & Seakeeping Tests : Water landing was initially studied with a computer simulation model which incorporated hydrodynamic impact theory. A subscale test program was subsequently conducted in a tank basin which included 60 drop tests with a full range of landing velocities and attitudes. Drops were made on both waves and calm water. Relatively low immersion depths and water spray loads confirmed that a deployable, lightweight, engine spray shield was feasible. Seakeeping tests in severe seas showed the module to be a stable, seaworthy configuration. Landing stability is enhanced and impact loads are minimized by using a proper parachute hang angle. Load and shock environment levels are less critical than other typical flight environments for launch vehicle equipment. Tipover rates were estimated at less than 2% for the wave and wind conditions in the recovery area.

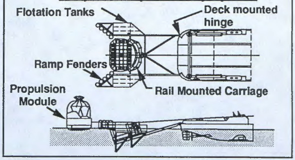
Test results provide high stabilty and low impact loads with use of parachute harness hang angle



Ocean Recovery Operations Tests : Validation of an ocean recovery approach was accomplished by a progression of concept studies, design, subscale model basin tests and open ocean recovery operations. System criteria were used to evaluate numerous concepts. The primary concept chosen for development was a buoyant ramp. The buoyant ramp is designed to provide compensation of wave induced motions between the propulsion module and the ship, thus, allowing an easy retrival of the module up the ramp and onto the ship. Recovery of the module with the ramp requires only onboard ship operations with a small crew. Subscale model basin recovery testing was performed and consistied of 200 individual tests with a full range of simulated wave and wind environments.

Recovery development culminated with 1/2 scale open ocean tests. Testing at 1/2 scale provided a realistic simulation of full scale recovery operations including crew and shipboard equipment interfaces. A 140 foot recovery ship was used with a 1/2 scale module. A series of towing, messenger line snare and recovery tests were performed. The final stage of the 1/2 scale recovery tests consisted of rough water recoveries with a buoyant ramp design based on model basin test results. Over 20 routine recoveries were performed in rough seas with waves to 12 feet high.

Buoyant Ramp Recovery System



This page summarizes a 10 minute video which will accompany the presentation